California Polytechnic State University

Senior Project

Direct Consumption of Photovoltaic Electricity in a Direct Current Water Heater

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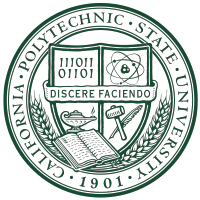


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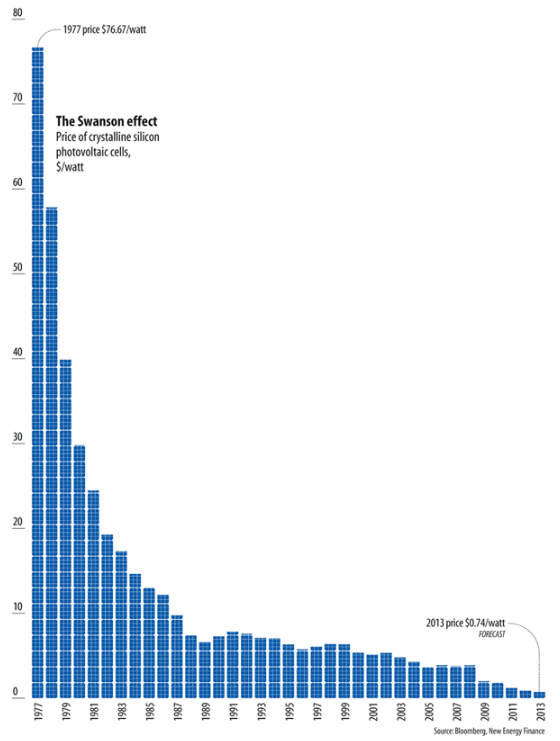
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**Abstract**

In extrapolating the continued decrease is solar electricity, we anticipate a day when people will forgo the cost of connecting to the grid to directly us photovoltaic (PV) electricity when it is available. In this scenario, the consumer will not be able to sell surplus PV electricity back to the utility, and may look for ways to store the “free” surplus electrical energy such as by heating water. To do this, we installed solar panels on a roof and connect it to a water heater to see if these systems could operate on the electricity generated from the solar panels. We calculated one panel should result in a temperature increase of 14 °C, which is in agreement with what we saw. Some considerations were how hot the water would get and/or how electronic feedback and control could be included. Our goal was to reduce the costs associated with having a photovoltaic system, so storing energy in batteries was ruled out.

**Introduction**

For the past 40 years, the cost of photovoltaics has been decreasing and if we continue this trend for another 10 years the cost of photovoltaic panels will be close to nothing (4). For this reason, we chose to investigate the possible uses of photovoltaics. In Figure 1, we see exactly how sharply the decrease in cost of photovoltaics has been since 1977.



**Figure 1**

After considering the cost of installation, the total price for solar panel will be cheap and allow access to an unlimited supply of clean renewable energy.

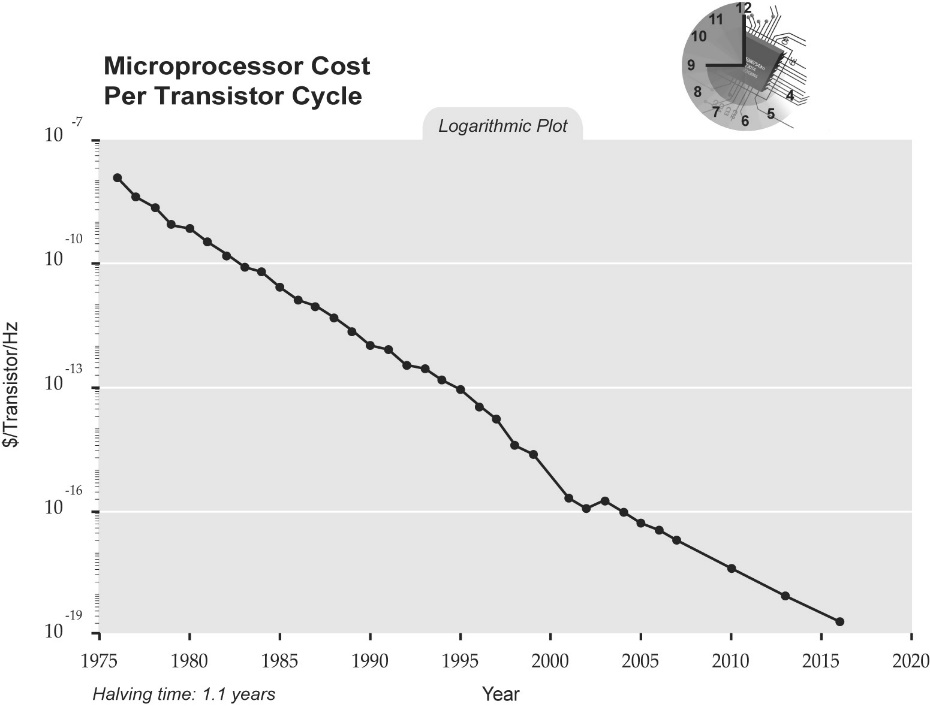
Certain states, however, have elected to increase the necessary cost to connecting to the grid. In states like Arizona and Nevada, laws have been passed to increase the cost of connection by 40%, making solar panel owners pay $40 to $100 dollars a month just to sell back the electricity generated by the panels (1) (2). These laws have acted as a deterrent for customers to get solar panels and has led to solar companies shutting down in these states.

There has always been a disagreement over the two different kinds of electricity; AC or DC. This arguments dates back to the late 19th century during the “war of currents”. During this time Thomas Edison would be advocating the use of DC current over AC. There were two rival companies driving the feud back then, Edison Electric Light Company and Westinghouse Electric Company. The Edison Company used DC current as distribution and made claims about how unsafe the use of AC was. The Westinghouse Company, who used AC current, started using transformers to step up and down the voltage that way power could be transmitted across power lines efficiently. This system turned out to be cheaper than transmitting DC current and that eventually led to DC being left by the wayside. As AC became more popular and expanding, our national electrical grid became only based on AC, which in turn led to household appliances being powered by AC current. DC is used for anything that runs off a battery and is the type of current produced by photovoltaics. In recent years, we have developed efficient DC-DC voltage converters, making DC transmission over distance cheaper. With this advancement, we would like to investigate the possible uses of DC current instead of being grid-tied and using AC. This will reduce the cost of our system because we will not be required to convert from DC to AC. For our purposes, heating a coil, DC will be sufficient. But what are we going to do with the electricity when we do not have an electrical load? We could choose to store the energy in a battery, but batteries can get expensive which is something we are trying to avoid. A possible use for this excess electricity would be to use it to heat water. A goal of this project is to investigate energy use in a cheap and efficient way that is also environmentally friendly. We would like to use optimize the energy from the photovoltaic panels and make sure we are using all the energy we get. We can achieve this by placing a heating coil in the combustion chamber of a water heater.

**Theory**

With access to almost free renewable energy in the next couple of years, we decided to determine if we could power a water heater using photovoltaics. We want our range in water temperature to be from 60 oF – 105 oF (15.5 0C – 40.5 0C) where 105 0F is considered hot to the touch and 60 0F is a typical resting temperature for water in a water heater without being heated. Although we could add extra solar panels, we decided to only use one in an attempt to simplify the project and verify that this process will work. To ensure that the household will still have access to hot water, we will lower the gas during the day but still have it running in case the solar panel does not produce enough power to have hot water. We will be using Sun Power E20-435W solar panels, so we should be able to get enough power to heat the water to a warm temperature. Another measure we are taking to not ruin the current gas heater is that we will not be hacking into the temperature settings of the water heater. Instead, to measure the temperature of the water we made our own data logger using an Arduino board.

Connecting a TMP 36 thermal resistor to the Arduino board, we programmed the Arduino to measure the temperature of the water tank using the resistance temperature relationship. Then, we had the Arduino write the data onto a SD memory card so that we could store large amounts of data. The program for the Arduino records the temperature every 5 seconds. We chose this method for data taking because it was cheap and efficient. In an attempt to lower the cost of our system as a whole we decided this was the best route to go. In past few decades, the price of microprocessors has been dropping exponentially. Similar to how photovoltaic costs have been dropping, microprocessors are becoming cheaper and easier to make. This has led to inventions like the Arduino board and its low cost. Figure 2 below shows just how much the price has been dropping over the years (3).



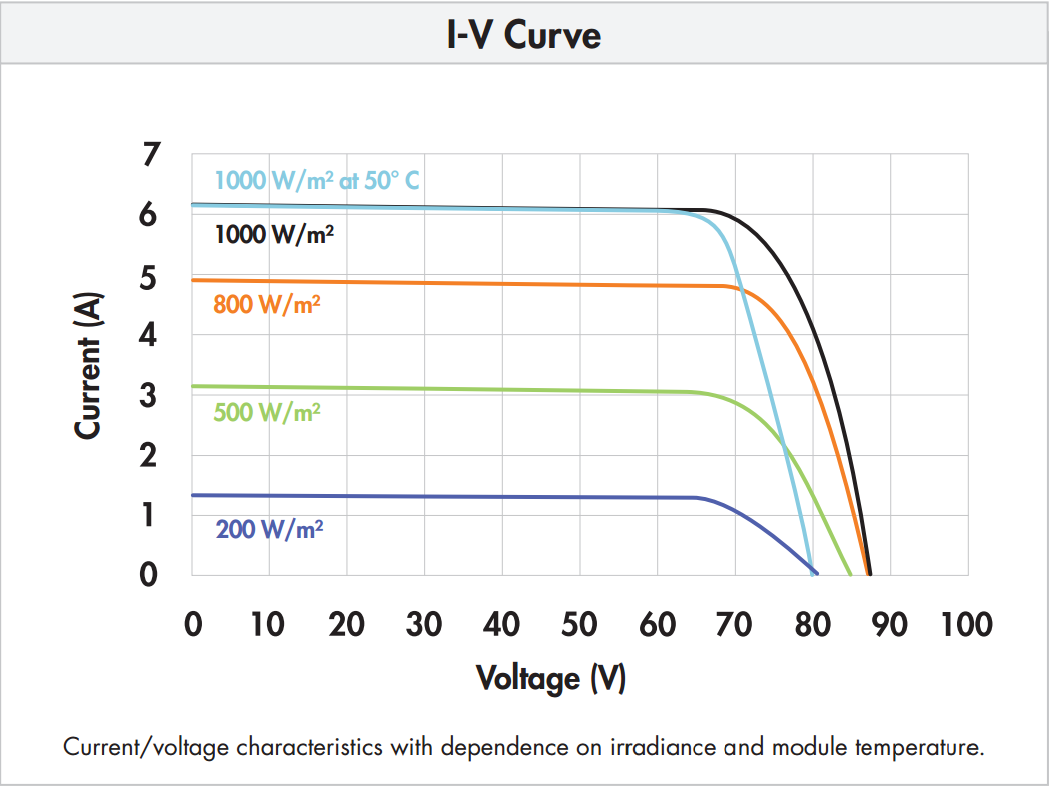
**Figure 2**

As Figure 2 shows, the cost of microprocessors has been going down meaning that society should start utilizing this commodity more. As we begin to investigate the possible uses of microprocessors, it is our goal to show that monitoring temperature can be one of those uses.

One problem will be that the panels do not provide electricity during the night. One option is that a person can buy battery packs so that when you are not using the electricity from the panels during the day, they charge the batteries, then during nighttime use the batteries to run the heater. This can be costly since multiple batteries would be required and batteries are not cheap. One other option is to make a system that uses electricity from the solar panels during the day and switches to the grid once the solar panels cannot generate enough electricity. This is a good option because the grid can be reliable and the only cost will be those acquired during the nighttime.

**Calculations**

One thing we had to decide on was how many panels we were going to connect to power the burner. To do this would require an IV curve for both the panel and the burner. The IV curve for the solar panel can be found on the manufacturer’s website and is shown in Figure 3 below (5).

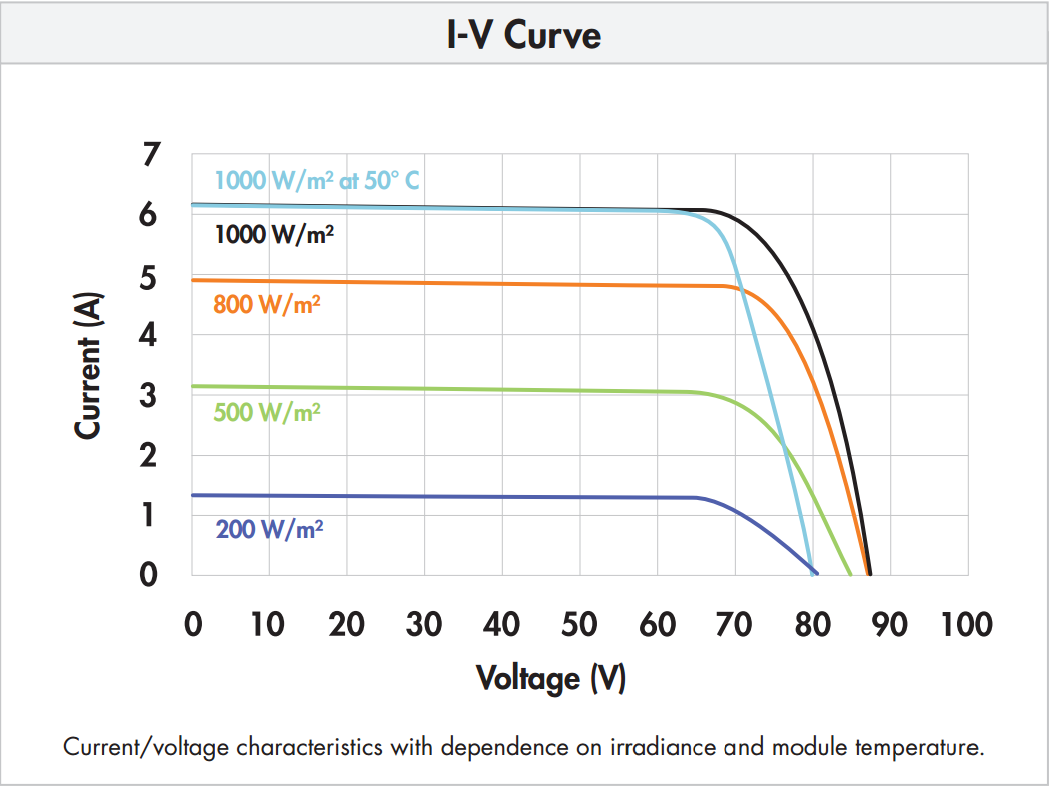


**Figure 3**

Next, we had to get an IV curve for the burner. We did this by connecting a variable power supply to the burner. We then measured the voltage and current going through the burner using multi-meters as we turned up the power. The IV curve for the burner is shown in Figure 4.

**Figure 4**

The burner should not necessarily behave according to Ohm’s Law because the burner heats up so one would expect the resistance to rise. We see that this effect is minimal. This graph also allows us to calculate the resistance of the burner, which turned out to be 14.8 ohms. To determine how much power the panels will produce, we would have to superimpose the IV curve from the burner onto the IV curve for the panels. Where the lines intersect will be the operating value of voltage and current going through the circuit. This can be shown in Figure 5 below.



The operational point is for the black curve, so we are looking at about 76 V and 5.1 A. Using the equation P = V\*I, we can solve for the power output of the panels. These values give us an operating power of 387.6 W. This is slightly below the rated wattage of 425 W, which one would achieve with a slightly lower resistance that would strike the rated PV output curve at about 70 V and 6.0 A. To calculate the amount of energy outputted by the panels, we must convert watts to joules per second then to joules per hour and multiply by how long the sun is shining. The calculations are shown below

We divided by a factor of 2 in order to average over the cosine of the angle between the incident sunlight and the perpendicular to the panel surface. This gave us a value for the amount of energy in total the panel should be outputting. With the equation Q = m\*c\*ΔT, we can calculate what the temperature change of the water should be. C stands for the specific heat of water, Q is the heat energy in joules, m is the mass of the water in kilograms, and ΔT is the temperature change in the water. We are heating a 29 gallon water tank, which equates to 109.8 kg of water, while the specific heat of water is 4186 joules per kilogram Celsius.

So this one panel will raise the temperature 10.7°C. If we start at a temperature of 40°C, by the end of the day the water temperature should be at 50.7°C.

**Design**

When originally discussing the directions we could go with this project, we decided to install 4 photovoltaic panels onto Dr. Schwartz roof. To simplify the project, we decided to only connect one solar panel to the burner. Figure 5 below shows us installing the panels on the roof and Figure 6 is what the panels looked like when finished.



**Figure 5**



**Figure 6**

Next, we measured the inside of the water tank’s combustion chamber to determine the size of our burner. We then took an Imusa electric burner and uncoiled it into the shape we had desired. Once we had the burner we had to decide how to get it off the ground. We took a sheet of stainless steel and cut out three small strips of it. We took the strips and bent them into little stands that the burner could rest on. From there, we had to install the burner in the chamber with the gas component. Figure 7 shows what the burner and stands look like inside the chamber without the gas component.



**Figure 7**

Once the burner was secured in the combustion chamber, we had to connect it all up. We used 10 AWG THHN (**T**hermoplastic **H**igh **H**eat-resistant **N**ylon-coated) wire to connect the panel to the burner. We included a manual switch in the circuit so that you could turn on and off the circuit if there was a problem. In Figure 8 shown below, the switch can be seen in the on position.



**Figure 8**

Something we had to consider was how the wiring was going to work in the chamber. The plastic insulation on the wiring was not going to be alright because it would melt in the chamber, but we wanted the wires to be insulated and protected. Also, we didn’t want to drill extra holes in the tank already. Our wires were not extremelly thick, so we decided to use the same the same hole the wires going to the gas burner use. We drilled two hole, one for each wire, and were careful to avoid any holes overlapping which would have caused the wires to come into contact easier. On the inside, we found wire insulation that was made to withstand the high temperatures inside the chamber. In Figures 9 and 10 below you can see both sides of the hole and the insulation covering the wire.



**Figure 9**



**Figure 10**

**Data**

The first day of data, displayed in Figure 11 below, was nice to see. We had spent most of a Saturday installing the burner and connecting it to the panels. To do this we had to have the gas heater turned off and removed from the tank. This caused the water temperature to be low to begin, starting at 35 °C. During the day we worked the data came out erratic, a factor of our moving things around. Consistency in the graph came at 8 o’clock once we had put everything together and turned the gas back on. There was a sharp rise in temperature because the water was heating back up and then some slow rising throughout the night. At around 9 o’clock the next day, the gas had been turned down and the switch to the panels had been turned on. The water appears to have cooled at this time, a result we believe was due to the panels not producing enough power yet. By the time 12 ‘o clock noon comes around, the panels began producing enough power the really heat the water tank. This came to a climax around 4 o’clock pm and afterward the temperature began to fall. We collected the data at 5 o’clock pm but left the panels on.

**Figure 11** The first day of data

Continuing on with the data appears in Figure 12 below. We left the panel on until after 7 o’clock pm once the sun had set. The gas was turned back on for the night, which led to the water temperatures steady rise. Again, on the 30th we can see the burner being turned on, a decrease then to a rise beginning just before noon. Once 4 o’clock pm passes, the temperature begins to decrease as the panel stops producing as much power and the water either cools from the ambient cool air or because someone draws some hot water from the tank. The 31st follows the same pattern that the previous days did as well, this time reaching slightly higher values. We believe this was due to the gas not being turned down exactly to what it was the previous day.

**Figure 12** The second and third days of data

After these days, we realized that there was a short in the circuit. The insulation for the wires in the chamber had shrank and left bare wire open on both sides. The bare parts of the circuit were touching the outside of the water heater, creating a short in the circuit. Once we fixed that issue, we gathered data for three more days. The data for these days when the circuit was properly connected is shown below in Figure 13.

**Figure 13**

**Figure 14**

In Figure 14 above, we have combined all the data into one graph. May 29th through June 3rd represents the days where the circuit was being shorted while June 7th through June 13th are the days where the burner was properly connected to the solar panels. The days between June 3rd and June 7th the burner was not connected to the panels because our switch had broken. This issue was resolved on June 7th.

**Analysis**

We measured the current and voltage going to the burner during the day and found the values to be 4.38 amps and 47 volts respectively. This corresponds to a power of 205.9 watts, roughly 180 watts below what we expected in our calculations above. Strangely, these readings indicate a resistance of 10.7 ohms, considerably less than we measured in the past for our filament. Looking at Fig. 4b, we notice that this data point doesn’t fall on the resistance curve. Additionally, we notice that this point would fall on a PV output curve corresponding to approximately 730 W/m2. Not surprisingly, this measurement was taken in the late afternoon, well after the sunlight fell perpendicular to the panel’s surface normal. Looking at Figure 13, the bumps in the afternoons of June 8th and 9th appear to be an increase of roughly 9 °C. We can attribute these increases to the burner because the temperature appears to be raising sharper than the rest of the time. Another reason to believe the bumps are a result of the burner is that there is a decrease in the late afternoon around sunset, when the solar panels would stop producing power.

Overall, the burner appears to have done its job in heating the water throughout the day. There were clear points of when the heater was working with very little gas burning, specifically between 12 and 4 on all the days data was gathered. The mornings did not seem to produce as much power as during the afternoon which is somewhat puzzling. This could be due to cloud coverage in the mornings and not in the afternoon. One other reason the mornings might not have produced the same power is because the solar panels are more westward facing than southern. Between cloud coverage and the angle the panels are at compared to the sun explain the temperature difference from morning to afternoon. Some days did seem to be hotter than others and there is a clear increase in the temperature as data is gathered. This increase may be due to the temperature sensor not properly connected to the water tank or the temperature sensor was broken.

**Conclusion**

In the near future, photovoltaics will be of negligible cost. The goal of this experiment was to investigate possible cost efficient uses of photovoltaic systems when the cost of the panels was taken out. We connected solar panels to a water heater in an attempt to run the system without storing energy. We considered the temperature ranges for the water heater since we didn’t want the hot water to be scalding hot. To ensure we wouldn’t get too hot, we only connected one panel up to the burner. If we were to try this again, adding more panels would be an area we could improve on. Also, if we were to reattempt this project, there are some things we’d do differently. For starters, we would have a guarantee that the temperature sensor was thermally connected to the water tank. One of our worries was that the temperature sensor was not connected properly to the tank. Since we had to cut out some insulation to put the temperature sensor in, we couldn’t be too sure that it was connected to the tank the entire time. Not having the sensor connected to the tank would result in temperature reading that is a weighted average between the water temperature and the air temperature. Another thing we could have done better was to add a multi-meter into the circuit that way we could get a live measurement of the power being produced by the solar panels. This would be beneficial because it would tell us that there was current flowing in the circuit and allow us to determine the power being produced from the panels. It would be nice to know that the panels were on and that the circuit functioned correctly.

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